Design of circular-shaped microstrip patch antenna for 5G applications

Mohammed Mahdi Salih Altufaili, Ameer Najm Najaf, Zainab Sabah Idan
Department of Computer Techniques Engineering, College of Technical Engineering, University of Alkafeel, Al Najaf, Iraq

Article Info

Article history:

Received Jun 30, 2021
Revised Dec 17, 2021
Accepted Dec 26, 2021

Keywords:

Circular geometry
Circular-shaped antenna
Computer simulation technology
Fifth generation
Microstrip
Microstrip antenna
Patch antenna

ABSTRACT

Using circular geometry has a great influence on many fields of science and engineering, one of which is antenna. Communication systems were oriented towards fifth generation (5G) because of large- bandwidth systems, compact requirements, high-data rates. In this research, a design and simulation are made to a microstrip circular patch antenna. The patch has two circles a compact structure of the first circle radius is 2.5 mm and second circle radius is 1 mm with thickness 0.35 mm. The proposed antenna has three resonant frequencies 41.08 GHz with a return loss of -12.4 dB, 47.4 at -18.86 dB and 54.4 at return loss -24.3 dB. The bandwidths are 150 MHz, 222 MHz and 219 MHz, the gains of three resonant frequencies are 6.16 dB, 9.89 dB and 5.54 dB, with efficiency of 98%. A technique of inset feed transmission line was utilized to match the fifty Ω microstrip feedline and the radiating patch. Based upon the proposed design, a Roger RT Duroid 5880 substrate that possesses loss tangent of 0.0009 with a height of 0.5 mm and a dielectric constant of 2.2 is employed. A computational process is conducted and analyzed by the use of computer simulation technology microwave studio.

Corresponding Author:

Mohammed Mahdi Salih Altufaili
Department of Computer Techniques Engineering, College of Technical Engineering,
University of Alkafeel
Al Najaf, Iraq
Email: mohammed.altufaili1987@gmail.com

1. INTRODUCTION

The research paper presents an introduction having overview of the significance of antennas utilized in various appliances, regarding theory of microstrip antenna, it is included in section 2. Section 3 focused on proposed design geometry, and results, conclusion are considered in sections 4 and 5 in turn. The antenna is a device used to convert electrical energy into electromagnetic energy to travel in free space, it acts as interface between two-guided devices. There is another definition by the Institute of Electrical and Electronics Engineers (IEEE) that the “antenna is a means to transmit and send radio waves”. It was also defined in a different way as a “metal device (wire or rod) for the transmission and reception of radio waves”, this definition is given by Webster’s dictionary [1].

Communications, whether wired or wireless, have been enabled among devices with polymorphous in the abilities and the dimensions, beginning from the central computer devices and laptops to the electronic devices used in the buildings, sensing components and mobile phones [2]. 5G network uses a variety of spectrum resources in millimeter waves, which is anticipated to considerably improve the communication capacity. Moreover, it will expectedly be capable of providing and supporting high data rates up to 100 times the capacity of the fourth generation [3], [4]. This brings new challenges to the network requirements and 5G communication system antenna design to fulfil the data rate and capacity that are expected. With the rapid

growth of 5G mobile data, many fields like Blockchain, artificial intelligence, realistic ultra-high definition and IoT services such as smart grids, smart transportation, smart cities would be remarkably optimized. With the development of mobile communication industry to utilize millimeter-wave spectrum, carriers would probably use 28-38-73 GHz band, which would become the obtainable band futuristic technology [5], [6].

Based on the requirements for 5G, antennas with light weight, low profile (compact size), low-cost mass production, ease of installation, conformable to planar surface and also non-planar surface, mechanically robust when mounted on rigid surface and compatible with monolithic microwave integrated circuit are quite important [7]. Despite of the bandwidth is narrow; it is possible to consider microstrip patch antenna (MPA) as an ideal candidate to fulfil the aforementioned requirements.

Aim of the work: 1) To design printed antenna with circular shape geometry to cover 41 to 54 GHz. 2) To evaluate a comprehensive study of results in terms of gain, bandwidth, reflection coefficient and efficiency. 3) By applying on the CST microwave studio 2018 simulator will obtain a band of frequency range for 5G applications.

2. THEORY OF MICROSTRIP ANTENNA

Upgrading in the global network would require instant transformations conducted to devices in order to have compatibility with the new network. It is very necessary to reconfigure all communication system, otherwise the new network will become redundant. Anyway, the rapid development will create changes to the antenna. Therefore, it is necessary to realize the necessity to design an antenna that works in 5G-communication range [8], [9]. Microstrip patch antenna (MPA) is one of the most widely used and most sought-after antennas in the field of communication because they are small and easily manufactured, light-weight, for that reason, these antennas are the preferred choice for most communications industries. With most of the modifications found in smartphones, their ability to minimize the entire circuit is considered as a key feature [10].

The notably increased demand for mobile, commercial and personal communication [11], such form of antenna with light, tiny structures has participated essentially in developing telecommunication systems of missiles and spacecraft [12]. Microstrip antenna radiates due to fringing fields among edges of patch and ground plane is presented in Figure 1. It is obvious that the fringing fields were not constricted in the insulating substrate only, but also are spread through the air. Therefore, the value of effective dielectric constant $\epsilon reff$ is a little smaller than the dielectric constant ϵr [13]. Fringing fields, from the patch, that accounts for the radiation, can be improved by having the patch width W increased, also by decreasing the value of dielectric constant ϵr or having the thickness of substrate h increased. Generally, microstrip antenna uses a patch with a larger width value and a lower value of dielectric constant and a thicker dielectric substrate [14]-[16].

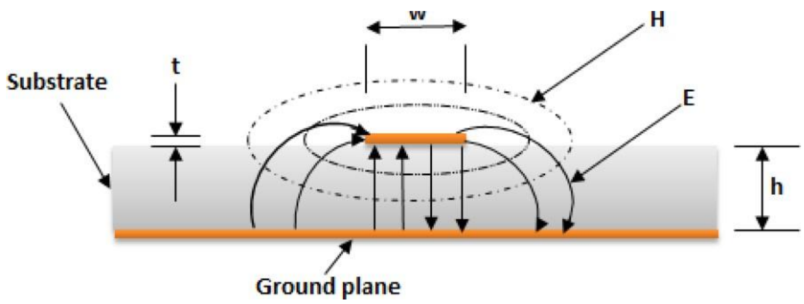


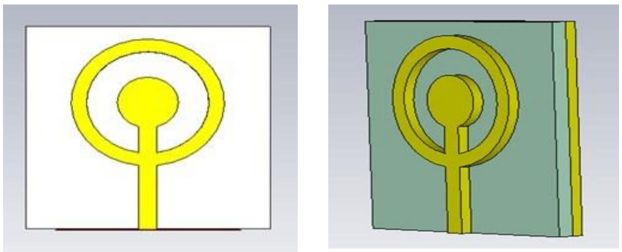
Figure 1. Fringing field for microstrip antenna

3. PROPOSED CIRCULAR MICROSTRIP PATCH ANTENNA (MPA)

The microstrip patch antenna is designed using two circles over a square -shaped ground plane. this design used small circular microstrip antenna in order to achieve triple band. This antenna is designed on Roger RT Duroid 5880 substrate having a small size of (8×8) mm^2, 0.5 mm substrate thickness h, 2.2 permittivity ϵr and 0.0009 loss tangent and the ground plane the same dimension of substrate is made of the electrical material copper with thickness 0.35. In addition, this proposed model is prepared for triple band the resonant frequencies 41 GHz, 47.4 and 54.4 GHz with an impedance bandwidth of 2 GHz. It is suitable for 5G applications such as radar, satellite communication and mobile phone. The overall view of the proposed design is illustrated in Figure 2 (a) illustrates the front view of the proposed design, while the Figure 2 (b) illustrates the side view of the proposed design [17]-[20].

3.1. Geometry of proposed microstrip patch antenna

The material of patch layer (upper layer) contains copper metal [21]-[23]. The proposed patch antenna 's dimension are the radius of large circle 2.5 mm and the radius of small circle 1 mm with thickness (t) 0. 35 mm. The purpose of the new design is for changing the existing distribution on the patch, which lead to enhance the radiation pattern and gain. Besides, in order to obtain the best solution to far-field and reflection coefficient S11, waveguide port is used. The (ground layer) consists of copper having dimension (8x8) mm^2, and the thickness is 0.35 mm. Table 1 shows the entire dimensions of microstrip antenna [24]-[26].



(a) (b)

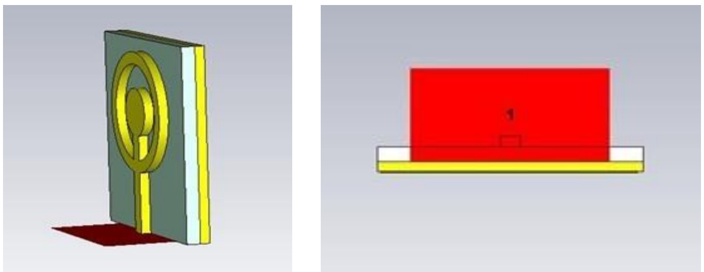
Figure 2. The proposed microstrip antenna of (a) the front view and (b) the side view

Table 1. The proposed fractal antenna dimensions

NO.	Parameters	Symbols	Dimensions
1	Length of ground	Lg	8 mm
2	Width of ground	Wg	8 mm
3	Length of substrate	L	8 mm
4	Width of substrate	W	8 mm
5	The radius of large circle	R1	2.5 mm
6	The radius of small circle	R2	1 mm
7	Length of feed line	Lf	4.1 mm
8	Width of feed line	Wf	0.6 mm
9	Thickness of ground and patch	t	0.35 mm
10	Thickness of substrate	h	0.5 mm

3.2. Waveguide port

The port that used in this proposed design named feed line waveguide port; the dimension of the port is $6 \times 4\ \mathrm{mm}^2$, the reason of usage of the waveguide port because it is considered the simplest type of the feed ports [27]. The current aforementioned feed line is considerably corresponded to the design proposed. The overall view of the proposed port design is highlighted in Figures 3 (a) and (b).



(a) (b)

Figure 3. Microstrip feedline waveguide port of (a) the side view feed and (b) feedline base

4. RESULTS AND DISCUSSIONS

This chapter presents the characteristics of proposed microstrip antenna, which includes reflection coefficient S11, VSWR, 2D 3D polar plot gain, 3D polar plot directivity, bandwidth and radiation efficiency [28]. The parameters are clarified in accordance to the results obtained. Thus, from parameters it can predict for enhancement for the futuristic work.

4.1. Reflection coefficient S11

The reflection coefficient wave S11 of the proposed microstrip antenna is shown in Figure 4. Frequency resonates at 41 GHz, 47.4 GHz and 54.4 GHz with reflection coefficient values of -12 dB, -18.8 dB and -24.36 dB, but the band width of signal is narrow. Resonant frequency of 54.4 GHz has the lowest S11 value.

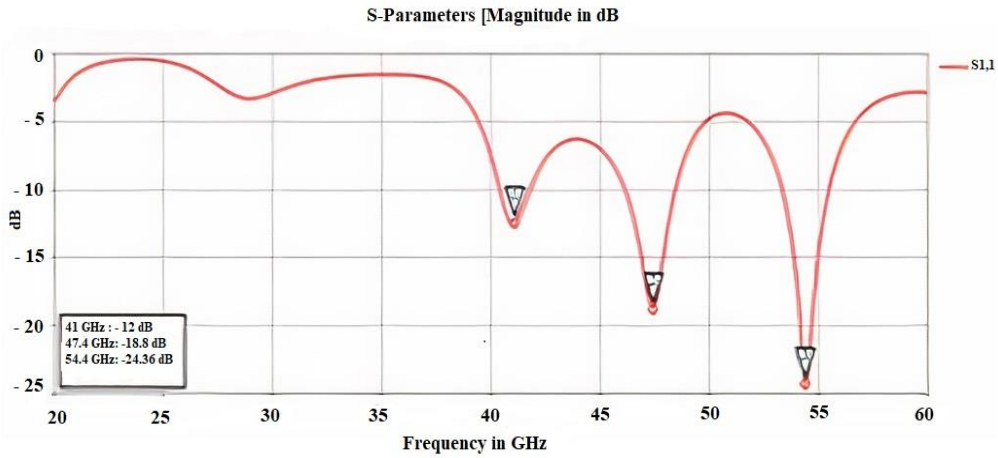
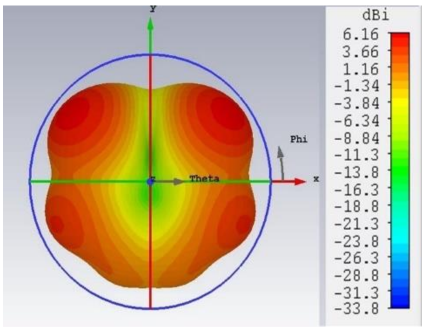


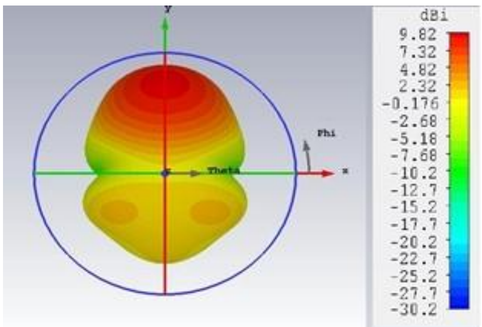
Figure 4. Reflection coefficient of small microstrip antenna

4.2. Polar plot gain

The 3D polar plot gain of the microstrip antenna design is shown in Figures 5 (a), (b) and (c) for triple resonant frequencies respectively. The gain at the first frequency, second frequency and third frequency 41, 47.4 and 54.4 GHz are respectively equal to 6.16, 9.82 and 5.54 dB. The 47.4 GHz gained the maximum gain among others.



(a)



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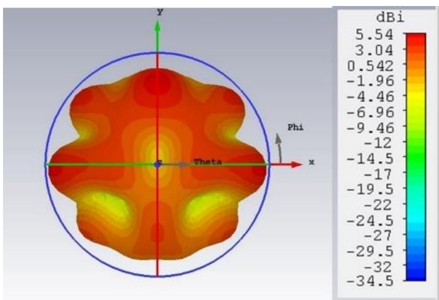
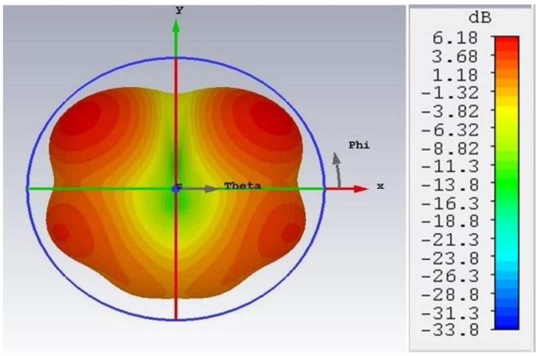


(c)

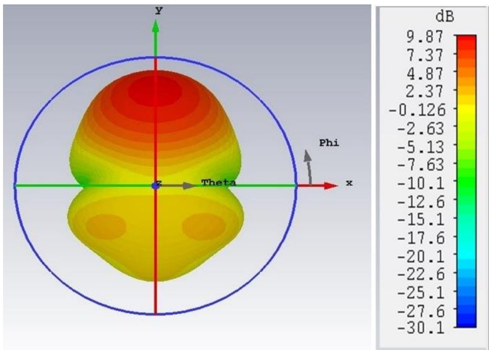
Figure 5. 3D Polar plot gain of various frequencies of (a) 6.16 dB at 41 GHz, (b) 9.82 dB at 47.4 GHz and (c) 5.54 dB at 54.4 GHz

4.3. Polar plot directivity

The simulated 3D far filled radiation pattern directivity of proposed antenna design at three resonant frequencies is shown in Figures 6 (a), (b) and (c) respectively [29]. At 54.4 GHz, the radiation pattern directivity is approximately wider than other. At 47.4 GHz resonant frequency, the directivity is somehow smaller than other frequencies.



(a)



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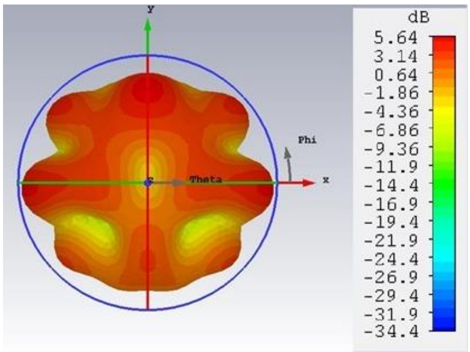


(c)

Figure 6. 3D Polar plot directivity of various frequencies of (a) 41 GHz, (b) 47.4 GHz and (c) 54.4 GHz

4.4. Bandwidth

From the higher frequency and lower frequency values, the calculated bandwidths of microstrip antenna, for three resonant frequencies 41, 47.4 and 54.4 GHz are 150-222-219 MHz as shown in the Figures 7 (a), (b) and (c). It can vividly be noticed that resonant frequency 47.4 GHz has the highest bandwidth. 41 GHz resonant frequency obtained the lowest bandwidth compared to others.

4.5. Efficiency

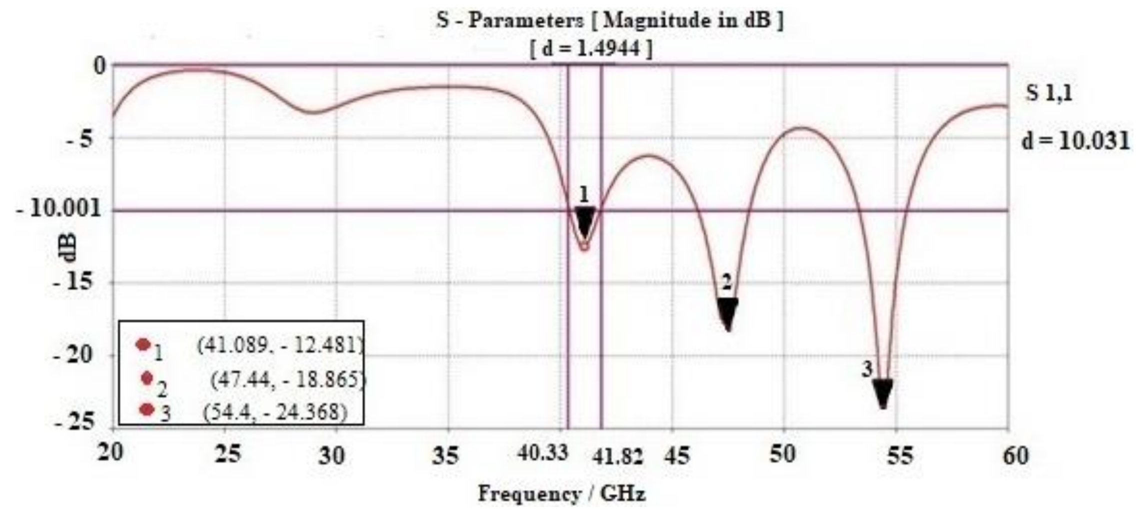
The efficiency of first band proposed design is 99.67%. It is calculated from the relationship between the gain and directivity, mentioned earlier. The efficiency of second band proposed design is 99.47 %, and the efficiency of third band proposed design 98.22%. So, based on these values, the first band proposed design is more acceptable than the second and third bands proposed designs.

4.6. Comparison between two bands

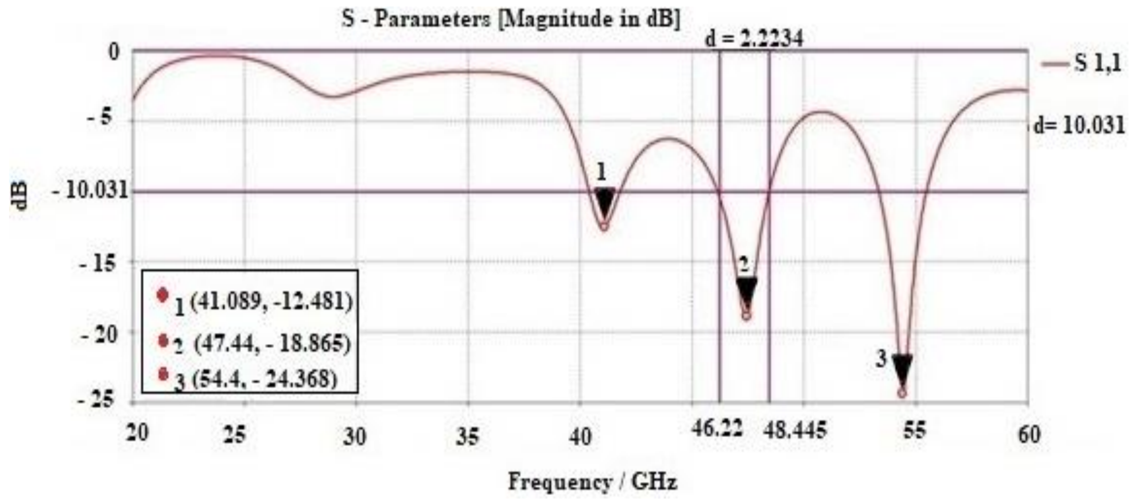
Table 2, shows the comparison between the three bands of the microstrip antenna of the proposed design. It can patently be noticed that the first band is as more efficient as the second and third respectively. However, the 47.4 GHz second band has greater gain, directivity and bandwidth, whereas the third band has the highest frequency and the lowest reflection coefficient in turn.

Table 2. Comparison between the triple bands

Name	Fr. (GHz)	S11 (dB)	Gain (dB)	Dir. (dB)	Eff. (%)	BW (MHz)
1^{st}	41	-12	6.16	6.18	99.6	150
2^{nd}	47.4	-18.8	9.82	9.87	99.4	222
3^{rd}	54.4	-24.3	5.54	5.64	98.2	219



(a)



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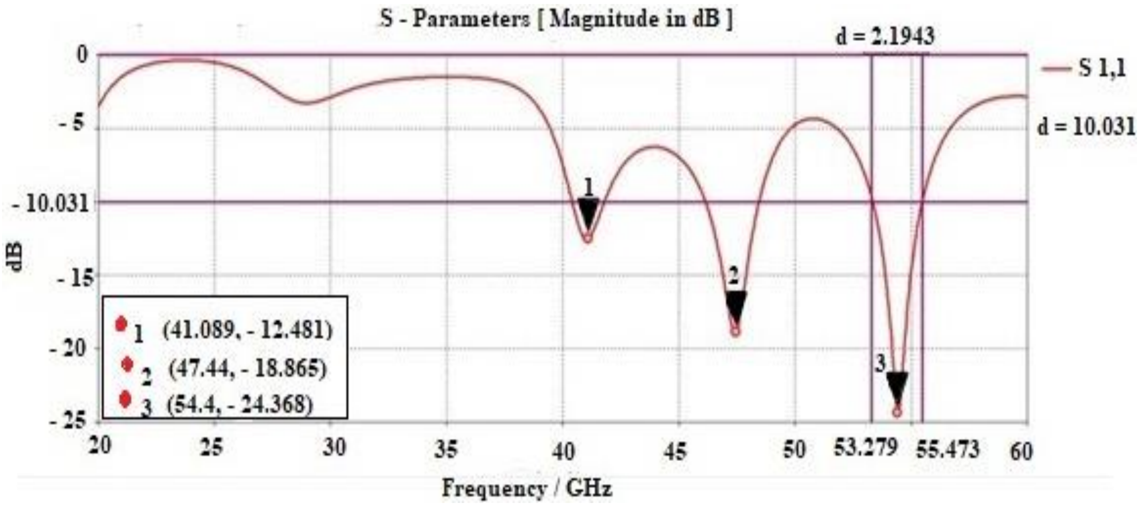

(c)

Figure 7. The bandwidths of three bands of (a) 150 MHz at 41 GHz, (b) 222 MHz at 47.4 GHz and (c) 219 MHz at 54.4 GHz

5. CONCLUSIONS AND FUTURE WORKS

The aforementioned proposed circular geometry patch antenna is designed and accurately simulated at the resonance frequencies of 41.08 GHz, 47.4 GHz and 54.4 GHz, using CST software. Results presented in this research, proposed to design circular microstrip antenna triple bands which are suitable for 5G applications. In addition, some concluding remarks are presented about the proposed design techniques. At the end of this chapter, some recommendations for future work are presented.

The suggestions for future work can be viewed as follows: 1) designing other types of antennas and obtaining their characteristics in an attempt to boost bandwidth and gain; and 2) combining more than one antenna to design an antenna array in order to enhance the gain and directivity to be suitable for applications, which requires high signal strength.

REFERENCES

[1] P. Kumar, A. Kumar, and P. Bhardwaj, "Design of double C-shaped microstrip antenna for application in UWB region," *2015 International Conference on Communications and Signal Processing (ICCSP),* 2015, pp. 0406-0408, doi: 10.1109/ICCSP.2015.7322918.

[2] X. Z. Zhu, J. L. Zhang, T. Cui, and Z. Q. Zheng, "A dual-broadband printed dipole antenna for 2G/3G/4G base station applications," *International Journal of Antennas and Propagation*, vol. 2019, 2019, doi: 10.1155/2019/4345819.

[3] J. G. Andrews *et al.,* "What Will 5G Be?," in *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065-1082, June 2014, doi: 10.1109/JSAC.2014.2328098.

[4] W. Roh *et al.*, "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results," in *IEEE Communications Magazine,* vol. 52, no. 2, pp. 106-113, February 2014, doi: 10.1109/MCOM.2014.6736750.

[5] T. S. Rappaport *et al*., "Millimeter wave mobile communications for 5G cellular: It Will Work!," in *IEEE Access,* vol. 1, pp. 335-349, 2013, doi: 10.1109/ACCESS.2013.2260813.

[6] S. Sridevi and K. Mahendran, "Design of millimeter wave microstrip patch antenna for MIMO communication," *International Research Journal of Engineering and Technology*, vol. 04, no. 10, pp. 1513-1518, Oct. 2017, [Online]. Available at: https://www.irjet.net/archives/V4/i10/IRJET-V4I10278.pdf

[7] X. Mavromoustakis, G. Mastorakis, and J. M. Batalla, "Internet of things (IoT) in 5G mobile technologies," *Springer*, vol. 8, 2016, doi: 10.1007/978-3-319-30913-2.

[8] M. Giordani, M. Mezzavilla, and M. Zorzi, "Initial access in 5G mmWave cellular networks," in *IEEE Communications Magazine,* vol. 54, no. 11, pp. 40-47, November 2016, doi: 10.1109/MCOM.2016.1600193CM.

[9] N. I. A. Ishak, N. Seman, and T. H. Chua, "Antenna array design with rectangular ring slot for 5G technology," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 17, No. 5, October 2019, pp. 2258-2267, doi: 10.12928/telkomnika.v17i5.12816.

[10] Y. Rahayu, H. Hazman, and R. Ngah, "Design LTE microstrip antenna rectangular patch with Beetle-shaped slot," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 15, no. 3, pp. 1083-1087, 2017. doi: 10.12928/telkomnika.v15i3.5493.

[11] V. Karthikeyan, S. Vignesh, K. A. Reddy, G. B. Reddy, and R. S. A. Sekhar, "A millimeter wave based circular slot loaded microstrip patch antenna for 5G communication," *IOP Conf. Series: Materials Science and Engineering,* 2019, doi:10.1088/1757-899X/590/1/012059.

[12] S. Nadhem, "Design and Analysis of slotted patch antenna for wideband applications," M.Sc. Thesis, Al-Mustansiriayah University, Department of Electrical Engineering, 2016.

[13] O. A. Safia, M. Nedil, L. Talbi, and K. Hettak, "Coplanar waveguide-fed rose-curve shape UWB monopole antenna with dual-notch characteristics," *IET Microwaves, Antennas & Propagation*, vol. 12, no. 7, 2018, doi: 10.1049/iet-map.2017.0852.

[14] V. -A. Nguyen, B. -Y. Park, S. -O. Park and G. Yoon, "A planar dipole for multiband antenna systems with self-balanced impedance," in *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1632-1635, 2014, doi: 10.1109/LAWP.2014.2347952.

[15] R. A. Fayadh, M. F. A. Malek, H. A. Fadhil, and F. H. Wee, "Planar finger-shaped antenna used in ultra-wideband wireless systems," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 12, no. 2, 419-428, 2014, doi: 10.12928/telkomnika.v12i2.71.

[16] A. K. Gautam, L. Kumar, B. Kumar Kanaujia, and K. Rambabu, "Design of compact F-shaped slot triple-band antenna for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 64, no. 3, 2016, doi: 10.1109/TAP.2015.2513099.

[17] N. Ferdous, G. C. Hock, S. H. A. Hamid, M. N. A. Raman, T. S. Kiong, and M. Ismai, "Design of a small patch antenna at 3.5 GHz for 5G application," *IOP Conf. Series: Earth Environmental Science,* 2019, doi: 10.1088/1755-1315/268/1/012152.

[18] R. K. Yadav, J. Kishor, and R. L. Yadava, "A Chaucer microstrip fractal antenna for mobile applications," *Journal of Communications Technology and Electronics, Springer,* vol. 61, no. 2, pp. 138-144, 2016. doi: 10.1134/S1064226916020054.

[19] S. Elajoumi, A. Tajmouati, Zbitou, A. Errkik, A. M. Sanchez, M. Latrach, "Bandwidth enhancement of compact microstrip rectangular antennas for UWB applications," *TELKOMNIKA Indonesian Journal of Electrical Engineering,*, vol. 17, no. 3, pp.1559-1568, 2019, doi:10.12928/telkomnika.v17i3.9184.

[20] G. Lovat, P. Burghignoli, and D. R. Jackson, "Fundamental properties and optimization of broadside radiation from uniform leaky-wave antennas," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 5, May 2006, doi: 10.1109/TAP.2006.874350.

[21] J. Colaco and R. Lohani, "Design and implementation of microstrip patch antenna for 5G applications," *IEEE Explore conference, 5th International Conference on Communication and Electronics Systems (ICCES)* 2020, doi:10.1109/ICCES48766.2020.9137921.

[22] M. Abirami, "A review of patch antenna design for 5G," *2017 IEEE International Conference on Electrical, Instrumentation and Communication Engineering (ICEICE),* 2017, pp. 1-3, doi: 10.1109/ICEICE.2017.8191842.

[23] Y. Rahayu and J. P. Putra, "Design of circular patch with double C-shaped slot microstrip antenna for LTE 1800 MHz," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 15, no. 3, pp. 1079-1082, 2017, doi: 10.12928/telkomnika.v15i3.5492.

[24] B. R. M. Ali, A. J. Alyasiri, and F. M. Ali, "A new design of microstrip Wi-Fi-shaped nanoantenna and microstrip Wi-Fi-shape slot

nanoantenna at THz region," *IOP: conference series*, doi: 10.1088/1742-6596/1529/3/032089.

[25] Krishnananda and R. T. S. Rao, "Design and performance analysis of slotted circular microstrip antenna," *International Conference on Microwave, Optical and Communication Engineering (ICMOCE), IEEE Xplore* 2015, 162-165, doi: 10.1109/ICMOCE.2015.7489715.

[26] J. Park, M. Jeong, N. Hussain, S. Rhee, P. Kim, and N. Kim, "Design and fabrication of triple-band folded dipole antenna for GPS/DCS/WLAN/WiMAX applications," *Microwave and Optical Technology Letters*, vol. 61, no. 5, pp. 1328–1332, 2019, doi: 10.1002/mop.31739.

[27] A. P. Kumar, D. M. K. Chiatanya, and D. Venkatachari, "Design of high gain dual T-shaped stub antenna for satellite communication," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 18, no. 3, June 2020, pp. 1209-1215, doi: 10.12928/telkomnika.v18i3.14992.

[28] M. K. Alkhafaji *et al*., "Study on the effect of the substrate material type and thickness on the performance of the filtering antenna design," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 18, no. 1, pp. 72-79, February 2020, doi: 10.12928/telkomnika.v18i1.13189.

[29] A. E. Fatimi, S. Bri, and A. Saadi, "UWB antenna with circular patch for early breast cancer detection," *TELKOMNIKA Telecommunication Computing Electronics and Controll*, vol. 17, no. 5, pp. 2370-2377, October 2019, doi: 10.12928/telkomnika.v17i5.12757.

BIOGRAPHIES OF AUTHORS

Mohammed Mahdi Salih Altufaili received M.Sc. degree in telecommunication systems and networks from Kharkiv National University of Radio Electronics/Kharkiv/Ukraine with the dissertation "Methods of interaction of PSTN with PLMN services". He is senior lecturer in department of Computer Engineering Techniques/College of Techniques Engineering/University of Alkafeel/Iraq. He is recently published a research paper in IOP conference proceedings regarding artificial nanosatellite, and participated in a conference in India/ICMETE-Springer regarding wireless fingerprint authentication, and participated in a research paper in University of Alkafeel conference/AIP. He can be contacted at email: mohammed.altufaili1987@gmail.com

Ameer Najm Najaf received M.Sc. degree in communication systems from Sam Higginbottom University/Allahabad/India. He is senior lecturer in department of Computer Engineering Techniques/College of Techniques Engineering/University of Alkafeel/Iraq. He is recently published a research paper in IOP conference proceedings regarding artificial nanosatellite with Mohammed Altufaili, and worked in quality assurance for college of engineering/university of Alkafeel. He can be contacted at email: ameer.zowarali@alkafeel.edu.iq

Zainab Sabah Idan received M.Sc. degree in communication systems from Imam Reza International University/Iran. She is an assistant lecturer in department of Computer Engineering Techniques/College of Techniques Engineering/University of Alkafeel/Iraq, as well as one of the managerial staff of aforementioned department. She can be contacted at email: zainabsabah@alkafeel.edu.iq